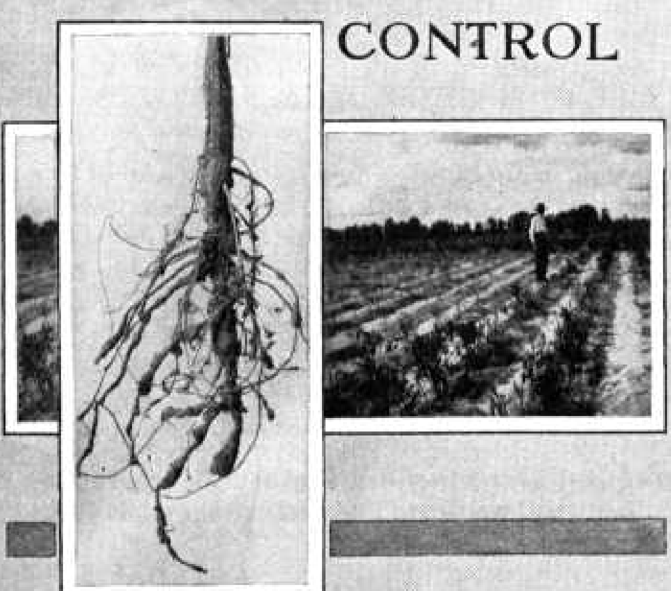
U. S. DEPARTMENT OF AGRICULTURE

FARMERS' BULLETIN No. 1345

ROOT-KNOT

ITS CAUSE AND CONTROL



ROOT-KNOT is too well known to need an introduction to most growers in the South or to commercial greenhouse men. Its wide range of hosts, the serious losses for which it is responsible, and its constantly widening spread into new localities prove it to be one of the most important of all plant diseases.

Once established in a field, this pest can be eradicated only by starving it to death by planting for two or three years crops not subject to infection, such as the large and small grains, a few of the leguminous crops, and special resistant varieties of others that have been developed by years of selection and breeding.

If a farmer is fortunate enough to have a field free from the disease in a locality where it is prevalent he would do well to stave off the evil day by studiously avoiding this original infestation. This may be accomplished by refusing any tubers, plants, or nursery stock that may be infested and by guarding against its introduction by way of farm implements, compost, manure, tools, or drainage water from diseased fields.

Greenhouse men should make a regular practice of sterilizing soil and seed beds where they have this pest to contend with.

Washington, D. C. Issued October, 1923

ROOT-KNOT: ITS CAUSE AND CONTROL.[1]

By G. H. Godfrey, *Pathologist, Office of Cotton, Truck, and Forage Crop Disease Investigations, Bureau of Plant Industry.*

CONTENTS.

INTRODUCTION.

ATTENTION should be directed to the continual spread of a common disease of plants generally known under the names of root-knot, root-gall, and big-root. It occurs as an out-of-doors pest in all except the most northern States, but it is most abundant in the more or less sandy land of the Atlantic and Gulf Coastal Plain regions, all the way from Maryland to eastern Texas, and in the lighter irrigated soils of the Southwest. Here and there it occurs to a serious extent in other parts of the South and West where soil conditions are unusually favorable, and even sometimes in the heavier soils where these are mixed with an abundance of organic matter and used year after year for susceptible crops. It is everywhere prevalent in greenhouses.

Root-knot is the cause of serious damage to many crops. The extent of this damage is difficult to estimate, since it is both direct and indirect and in many cases is overlooked entirely. The direct damage is that caused to the growing crops. The indirect damage results from the fact that the presence of the disease makes it impracticable to grow certain crops which are particularly susceptible to injury.

Careful estimates made on the basis of actual surveys through typical agricultural counties in the Southeast have shown the direct losses due to reduced yield to be enormous. The losses in some cases ran as high as 80 per cent. The loss for cotton in all sandy lands in a single county in South Carolina was estimated at 4.4 per cent. For Georgia the cotton root-knot loss in 1917 was estimated at 4.1 per cent of the crop. Based on these figures, the annual losses in cotton-growing areas known to be infested with root-knot in the entire South were estimated to be approxi-

[1] This is a revision and extension of Farmers' Bulletin 648, "The Control of Root-Knot," by Ernst A. Bessey and L. P. Byars, issued April 1, 1915.

mately 200,000 bales of cotton and 100,000 tons of seed. Careful surveys through certain trucking districts of the South showed losses to be even greater in the aggregate for truck crops. In one county in Florida, for example, losses in snap beans were estimated to be 20 per cent; in cabbage, 1 per cent; in celery, 14 per cent; in eggplant, 21 per cent; in potatoes, 12 per cent; in lettuce, 8 per cent; in peas, 25 per cent; in tomatoes, 13 per cent. Based on prices that were in effect at that time, losses in these and other truck crops not listed amounted to approximately $150,000. Similar figures were obtained from other sections in the Southeast.

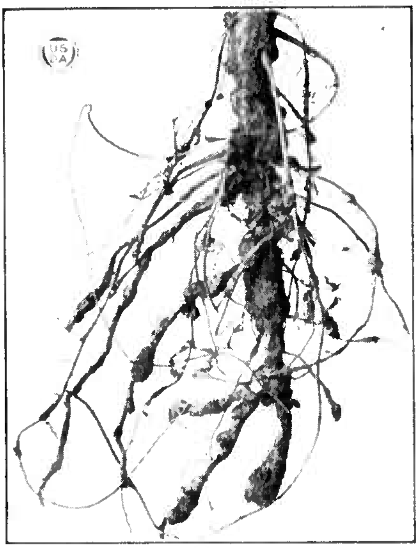


FIG. 1.—Root-knot of the cowpea, showing enlargements caused by the root-knot nematode. All varieties of cowpeas except the four listed in this bulletin are very susceptible to root-knot and should not be used in rotations just preceding cotton or other susceptible crops or as green-manure crops in peach orchards. The four varieties mentioned or other resistant crops should be used instead.

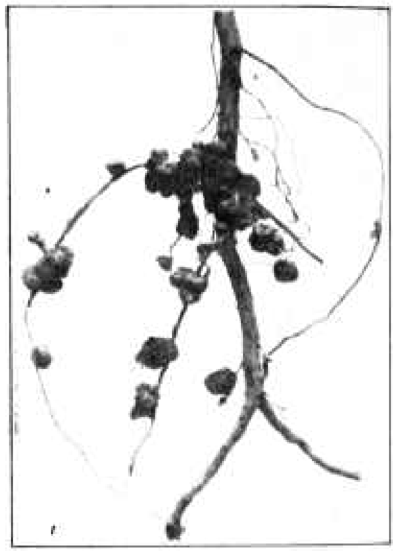


FIG. 2.—Spherical nodules on cowpea roots produced by beneficial nitrogen-fixing bacteria. These enlargements should not be confused with the injurious root galls shown in Figure 1 that are caused by the nematode.

The Southwest also suffers enormous losses. The disease is coming to be a limiting factor in melon production in some parts of southern California. Likewise truck-crop growing in general and potato growing in particular in some of the delta regions of California are menaced. Some nurseries are meeting with heavy losses, owing to the restriction that is placed on the sale of any kind of stock that is infested with the root-knot organism. Figs, grapes, peaches, and walnuts are among the crops sustaining losses in this connection.

APPEARANCE OF PLANTS ATTACKED BY ROOT-KNOT.

As a rule, root-knot produces no malformations or enlargements on the parts of the plant above ground and consequently is frequently overlooked. However, plants badly infested are dwarfed, wilt

readily in hot, dry weather, and are usually a paler green than healthy ones. Where the attack is most severe, plants may be entirely killed. In the case of a mild attack, only a small amount of dwarfing, together with a reduction in yield below the normal, is noticeable. Sometimes even the dwarfing is absent, and the reduction of yield is not noticed. Since the disease is widely prevalent in some districts, the reduced yield is supposed by the growers to be a normal one.

On examining the roots of an infested plant the presence of the disease is usually very easily detected. Depending upon the severity of the attack, the fine feeding roots, as well as some or all other roots, will be found to be greatly enlarged at various points. These enlargements may be scattered or they may be so close together that the whole root system is abnormally thickened. Plants affected in this way are frequently said to have clubroot, although the true clubroot is a disease due to an entirely different cause and is confined to plants of the mustard family. Root-knot enlargements in legumes, such as the cowpea and clover, are sometimes confused with the beneficial nodules caused by the nitrogen-fixing bacteria which live in the roots of these plants. Nodules produced by the nitrogen-fixing bacteria are spherical or lobed, small or medium sized, and attached to the sides of the rootlets, from which they may be easily detached. The root-knot parasites, on the contrary, cause swellings in the roots themselves, which can not be broken off readily. They vary greatly in size, from small

FIG. 3.—Root-knot of cotton. The root-knot parasite may occur in such small numbers as not to be very serious in itself, yet the injuries to the roots caused by it furnish a vulnerable point of attack for the wilt fungus; hence, root-knot in combination with the fungus disease greatly reduces the yield.

swellings in the fine hair roots to great knobs an inch or two in diameter. The pronounced difference in appearance between the injurious root knots and the beneficial root nodules can be seen by comparing Figures 1 and 2, showing cowpea roots, and by studying the various root-knot illustrations, Figures 3 and 10 to 21.

The galls on roots diseased with root-knot, as shown in Figures 1 and 3, interfere with the transfer of water from the fine feeding roots to the stems and leaves, with the result that in rather dry weather on a hot day the plants may wilt through failure to secure the proper quantity of water, even though the soil may be quite moist. Furthermore, the diseased tissues are quite watery and more easily permit the entrance of fungi or bacteria which cause decay, so that the death of the plant may be due immediately to the nematodes themselves or to other parasites that gain entrance to the plant

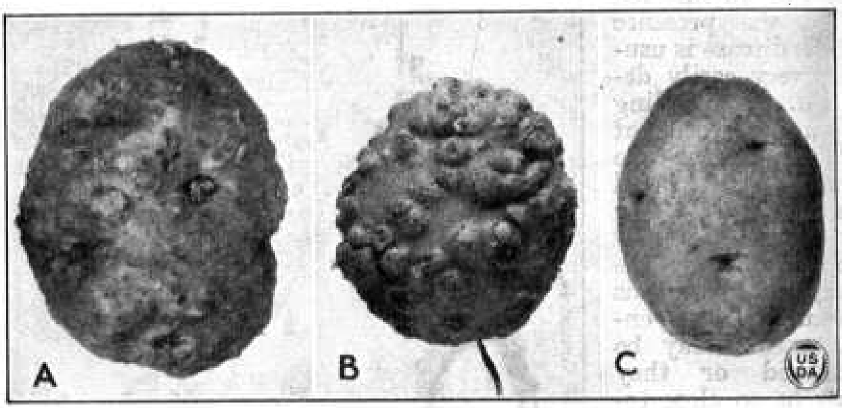


FIG. 4.—Two potatoes, *A* and *B*, badly infested with the root-knot nematode, and one, *C*, free from infestation. The roughened, warty, and discolored surface of the infested tubers are the external signs which indicate the presence of the parasite in the interior. Such diseased tubers are unfit for table use and should never be used for seed purposes. Slightly infested tubers may not show the external symptoms. They are just as capable of starting the disease in a new field, however, and their use as seed should be avoided.

through the injured tissues. A good example of this is often seen in the case of cotton, on which the root-knot parasite alone may be present in such small numbers as not to be particularly harmful beyond reducing the yield somewhat. Yet the injuries to the roots due to this parasite make it possible for the fungus that causes the wilt (black-root) of cotton to gain entrance to the roots much more readily than if the root-knot parasite were absent. Thus, root-knot in combination with this fungous disease greatly reduces the crop.

It has been repeatedly demonstrated that it is not profitable to attempt to grow even wilt-resistant varieties of cotton on land infested with root-knot without first rotating with immune crops to reduce the number of nematodes.

It is not always the roots that bear the most conspicuous and harmful effects of root-knot. In certain tuberous plants, like the Irish potato, the swellings on the rootlets may be small, while the tubers when thoroughly infested with the disease are much roughened, discolored, and warty on their surfaces, as shown in Figure 4. By cut-

ting open these potatoes a layer of discolored tissue, which contains the parasites in large numbers, is usually found just beneath the skin. (Fig. 5.) Such tubers are not only undesirable for table use, but are also wholly unfitted for seed purposes, since they carry the cause of the disease and spread it into uninfested districts.

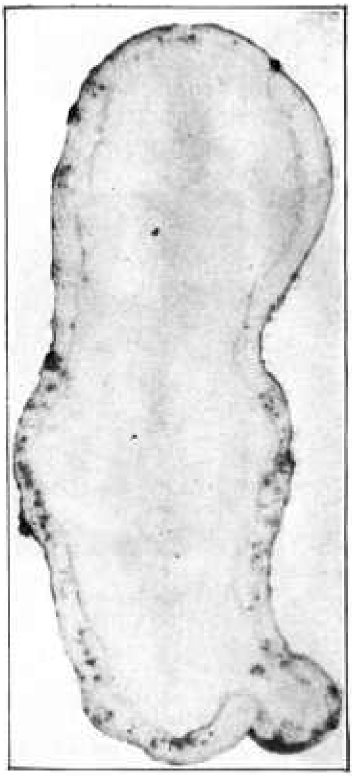


FIG. 5.—Half section of a potato invaded by the eelworm. Just beneath the surface of the tuber is a ring of discolored tissue which contains large numbers of these worms. Planting such tubers spreads the disease rapidly. (After W. A. Orton.)

CAUSE OF ROOT-KNOT.

Root-knot is caused by a minute animal, *Heterodera radicicola*. In the earlier stages of its development this animal is wormlike, and for this reason has been called an eelworm. On account of its production of galls, it may be called the gallworm. It belongs to the group of animals more correctly known as nematodes, many of which are injurious to plants, while numerous others attack animals. The particular species under consideration is found widespread over most of the temperate and tropical parts of the world where the conditions are favorable for its development. Its life history[2] is briefly as follows: Hatching from an egg which is usually less than one two-hundred-and-fiftieth of an inch in length, it is a small, wormlike creature between three and five times as long as the egg; that is, about one-eightieth to one-fiftieth of an inch in length. The diameter of the body is about one-thirtieth of the length. On account of their minuteness, these nematode larvæ are invisible to the unaided eye. They move through the soil with considerable activity, and on finding a root of a susceptible plant, preferably a young feeding root, bore their way into it, usually near its tip. Once inside, the young nematode ceases its active movements, begins to enlarge, and by means of a hollow, spearlike organ within its mouth absorbs its nourishment from the root. A greatly magnified egg is shown

FIG. 6.—A newly deposited egg of the root-knot nematode, magnified 400 times. These eggs are produced in large numbers, some females laying as many as 500. Because of their tough covering, the eggs are resistant to most chemical treatments and to adverse soil conditions. (After N. A. Cobb.)

[2] Additional information concerning the life history of this parasite, with a list of susceptible plants and details of experiments in controlling the nematode in the southeastern United States, may be found in Bulletin 217 of the Bureau of Plant Industry, Root-Knot and Its Control, by Ernst A. Bessey, issued November 21, 1911.

in Figure 6, and in Figure 7 both eggs and larvæ magnified about 30 times may be seen.

The presence of the nematode in the root irritates the tissues in such a way that the root enlarges, forming a swelling that may be two or three times as thick as the diameter of the root above or below. If many nematodes are present in the root the swellings may become very large, especially as the root increases in age. The female nematode within the root increases in thickness more rapidly than it does in length, so that eventually it is almost pear shaped and large enough to be visible to the naked eye, becoming from one-fortieth to one-twenty-fifth of an inch in diameter. When a root badly infested with these nematodes is broken open at this stage, the mature

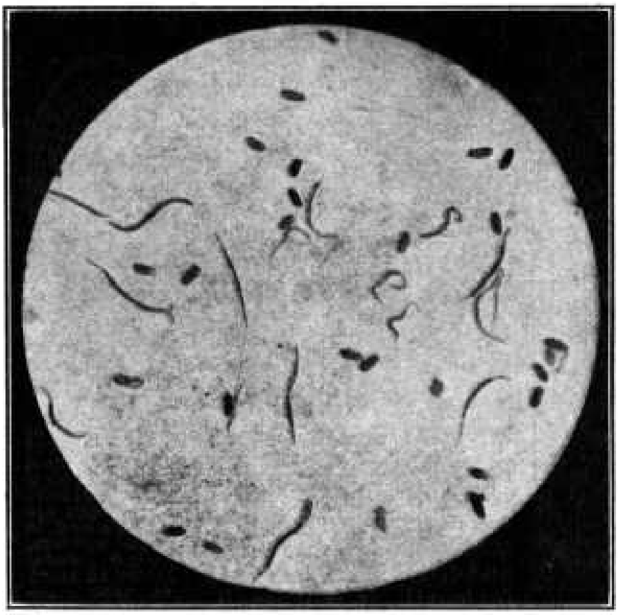


FIG. 7.—Illustration made from a photomicrograph of the eggs of the eelworm and the young worms just hatched, taken from a potato. It is in this worm stage that the parasite moves through the soil and enters the roots or tubers of plants. (After F. B. Headley.)

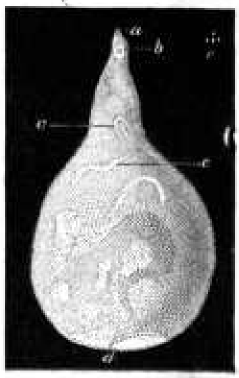


FIG. 8.—A female of the eelworm (*Heterodera radicicola*) magnified 85 diameters: *a*, Mouth; *b*, spherical sucking bulb; *c*, *c*, ovaries, as seen through the body wall; *d*, anus; *e*, small white spots showing approximately the natural size of these worms. During the egg-laying period they are usually a glistening white and can be readily seen with the unaided eye by carefully breaking open an infested gall. (After N. A. Cobb.)

females, as shown in Figure 8, can frequently be observed as minute, pearly white, rounded bodies from one-fourth to one-half the diameter of the head of a common pin. Figure 9 shows several of them in a small bit of infested tissue. It requires about four weeks for the female to reach full development and begin laying eggs. The female is capable of laying more than 500 eggs, each of which may hatch into a wormlike larva, as mentioned above.

The males are rarely seen except when searched for at just the right period. Their development up to a certain stage is like that of the female; that is, the larva enters the root in the same way and enlarges within it, but after becoming much elongated and shedding

a skin it bores its way out of the root into the soil again. It is then a wormlike animal one-sixteenth to one-twentieth of an inch in length, but not over one-fortieth as thick as it is long. It is practically invisible to the naked eye.

In the warmer climates, such as southern Florida, southern Texas, and parts of California, it is possible for the nematodes to pass through as many as 10 to 12 generations in a year, but in the cooler climates the number is less. The number of generations is governed by the temperature, since the nematodes do not develop except when the soil is warm. Thus, in northern Florida, December, January, and February are months in which little nematode injury occurs. In South Carolina the comparatively quiescent period lasts from

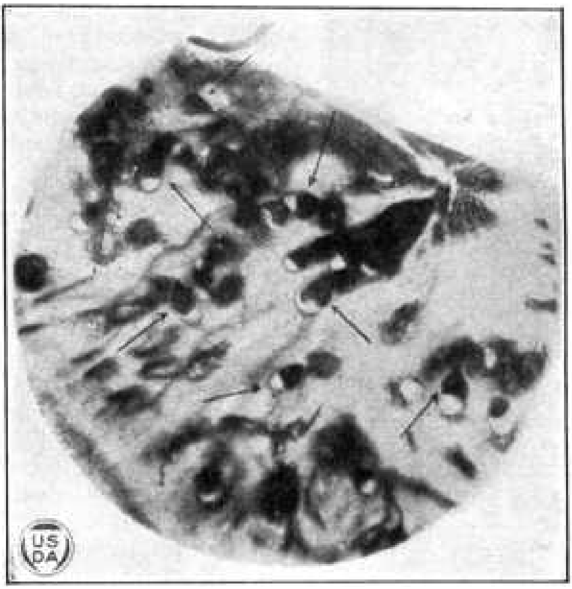


Fig. 9.—Highly magnified section of a severely infested sugar-beet root, showing the numerous adult female nematodes embedded within the tissue. This illustration represents an area about one-fourth inch in diameter.

the middle of October to the middle of April, and in New York, Michigan, and Colorado the active period is probably not much longer than the three warmest summer months.

PLANTS ATTACKED BY ROOT-KNOT.

The root-knot nematode attacks a large number of plants of widely different types. The kinds of plants on which it is known to occur number over 500, and doubtless future observations will greatly extend this list. Among those subject to attack are many in which the nematodes inflict no visible injury upon the plants, being found only in a few of the smaller roots in such small numbers that they are negligible, as far as the plant is concerned. Many of the common

weeds belong to the class of plants which harbor the nematodes and at the same time show few of the symptoms. However, such plants are dangerous from the farmer's standpoint, since they help to keep the soil stocked with the nematodes. When it is considered that one female may produce more than 500 eggs, it is evident that not many individuals are required to keep the ground thoroughly infested. The young nematodes are able to exist in the soil for more than a year, working their way through it during the warm weather in search of roots into which they may enter. For this reason it is important to keep the ground free from the plants upon which the nematodes feed.

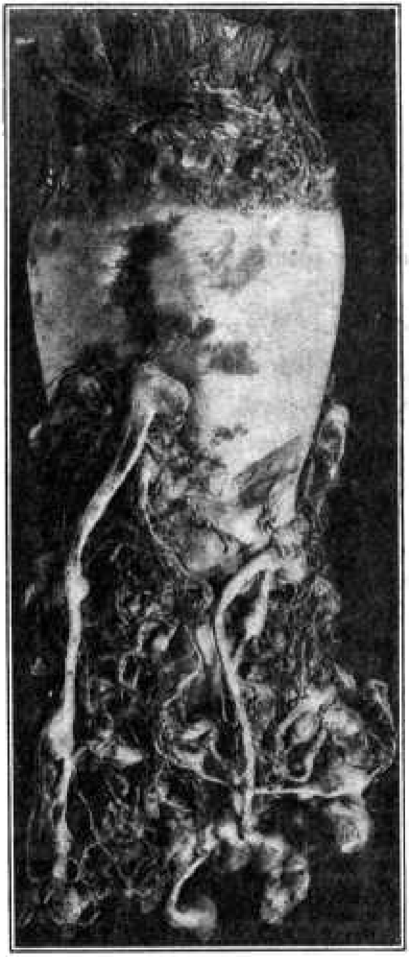


FIG. 10.—A sugar beet affected with root-knot. In certain sections of the Southwest the growing of sugar beets has been prevented by this disease.

Besides the plants that are only slightly infested some are found in which the nematode galls are very abundant on the roots, yet with no apparent damage noticeable in the crop. Such plants, perhaps, make up the majority of the susceptible ones. There is a third class, however, in which the nematode injury is very severe and easily noticeable. Such plants make poor growth, are stunted, give reduced crops, or are killed prematurely, while the roots are found to be masses of swollen structures scarcely recognizable as roots. In badly infested areas the sugar beet, squash, tomato, lettuce, muskmelon, and celery, as illustrated in Figures 10 to 15, present all the root symptoms described for this third class of plants. Somewhat less conspicuously, the effect of the parasite upon woody plants, such as the grape, willow, and fig, is shown in Figures 16, 17, and 18. In Figures 19, 20, and 21 the results of gallworm infection of the primrose, chrysanthemum, and carnation are clearly shown.

A large number of the commonly cultivated plants are more or less subject to the disease. The classified list which follows includes the more important, highly susceptible plants. These should never be grown on infested fields or transplanted from any field that may possibly contain the parasite.

PLANTS SUBJECT TO ROOT-KNOT.

Field crops:
- Alfalfa.
- Clover.
- Cotton.
- Cowpea (except Iron, Brabham, Monetta and Victor).
- Field pea.
- Flax.
- Pumpkin.
- Soy bean (except Laredo).
- Sugar beet.
- Sugar cane.
- Sweet potato.
- Tobacco.
- Vetch.

Ornamental and drug plants:
- Begonia.
- Cineraria.
- Clematis.
- Coleus.
- Dahlia.
- Hollyhock.
- Ginseng.
- Goldenseal.
- Peony.
- Rose.
- Sweet pea.
- Violet.

Truck crops:
- Asparagus.
- Bean.
- Beet.
- Cantaloupe.
- Carrot.
- Celery.
- Cucumber.
- Dasheen.
- Eggplant.
- Garden beet.
- Garden pea.
- Lettuce.
- Muskmelon.
- Okra.
- Onion.
- Pepper.
- Potato.
- Salsify.
- Spinach.
- Strawberry.
- Tomato.
- Watermelon.

Woody plants:
- Almond.
- Catalpa.
- Cherry.
- European elm.
- Fig.
- Mulberry.
- Old World grapevine.
- Peach.
- Pecan.
- Persian walnut.
- Weeping willow.

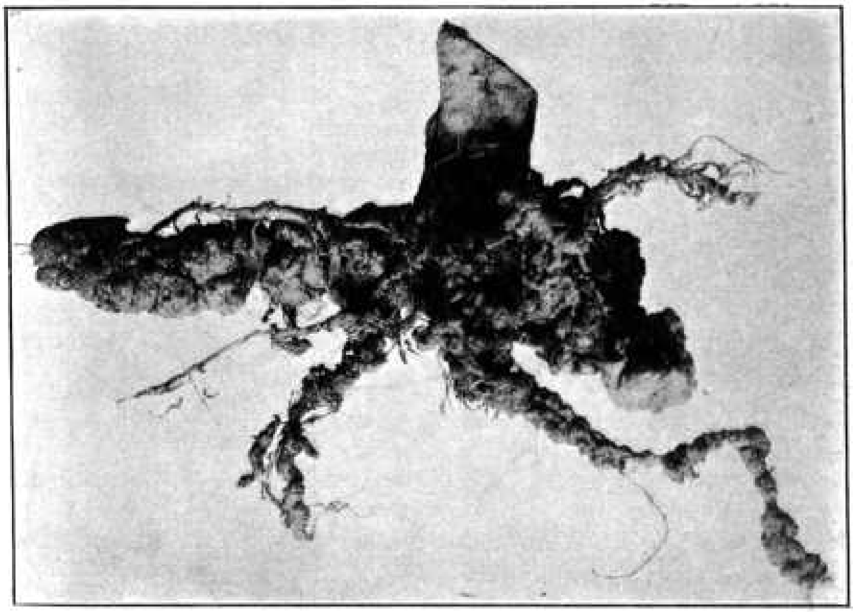


FIG. 11.—Squash roots affected with root-knot. The entire root system has become infested with the parasite; hence, the proper amount of food material does not reach the parts of the plant above ground.

Besides the above-listed plants, most of the common weeds are attacked by the nematodes, some of them very severely. Such weeds are a constant source of danger to the farmer, as they help to increase the number of nematodes in the soil. An abundance of weeds is a sign of poor agricultural practice anywhere, but weeds become doubly dangerous where they not only do harm by crowding out other plants and using up food intended for them, but also multiply a pest which may later destroy the planted crops.

PLANTS NOT ATTACKED.

Fortunately, many plants of economic importance are known to be free from the attacks of root-knot. As will be shown later, advantage is taken of this fact in controlling the disease. The following list includes the more important cultivated plants which, so far as known, are seldom or only slightly affected by the nematodes and may be used in crop rotations with the expectation of greatly reducing the number of eelworms.

PLANTS IMMUNE OR ONLY SLIGHTLY SUSCEPTIBLE TO ROOT-KNOT.

Barley.
Beggarweed.
Broom-corn millet.
Chufas.
Corn.
Cowpea, Brabham, Iron, Monetta, and Victor varieties.
Grasses (nearly all).
Kafir.
Milo.
Natal grass.
Peanut.
Pearl millet.
Redtop.
Rye.
Sorghum.
Soy bean, Laredo.
Timothy.
Velvet bean.
Wheat.
Winter oats.

FIG. 12.—Roots of a tomato plant completely invaded by nematodes. Most varieties of tomatoes are severely attacked by the parasite. (After George F. Atkinson.)

FIG. 13.—A lettuce plant infested with the eelworm. Almost all other common garden plants are likewise attacked. Their roots furnish excellent feeding and breeding places for the parasite.

CONDITIONS FAVORING ROOT-KNOT.

Root-knot is seldom found in heavy soils, apparently because it is difficult or almost impossible for the young nematodes to make their way from one root to another through such soils. Occasionally a garden in such soil which has been made lighter by repeated applications of manure or other humus and frequent culti-

vation and into which the pest has been introduced may gradually become badly infested. This accounts for some of the reports of the disease in localities not ordinarily considered subject to it because of generally unfavorable soil conditions. Most root-knot occurs in light soils, especially those of a very sandy nature. There is therefore much more risk of infestation in growing susceptible plants on light sandy soil than on those which are heavy or stiff. Where the land is water-soaked for a considerable period of the year these nematodes are not abundant or do not occur at all, nor are they found, on the other hand, in land that is exceedingly dry. Warm soil is necessary to their development. Below 55° F. the nematodes, even if present, are relatively inactive, and very little infection occurs. Above that point their activity is great up to the maximum temperature for the growth of any of their host plants. Since 55° F. is none too low for the growing of many crops, this knowledge can sometimes be applied successfully in growing susceptible crops on infested ground. Thus, celery and lettuce can be grown during the fall, winter, and early spring on infested land in some parts of Florida. The same land planted to tomatoes, eggplant, or okra later in the season when the soil is warm produces plants greatly damaged by root-knot. Likewise in a greenhouse lettuce can be grown in soil that has shown itself to be infested with nematodes provided the soil temperature is not permitted to go above 55° F.

Fig. 14.—Roots of a muskmelon plant, showing enlargements due to the eelworm. Other truck and field crops are similarly attacked and should never be planted two successive years on infested land.

Severe freezing of the ground kills out most of the nematodes near the surface. The infestation may survive even the most severe winters, however, provided the soil is the proper type to permit the nematodes to reach a considerable depth. Carried thither by their own activities and by movements of the soil water, they live over in an inactive condition. Upon the return of a favorable environment the following season, those that have survived resume their activity and infest such susceptible plants as may be available. Thus, they are found to an injurious extent at times in such Northern States as Michigan, Nebraska, Colorado, Utah, and Idaho. Here, however, only one or two generations develop during the summer, owing to the shortness of the season, and they never become exceedingly abundant unless other conditions are unusually favorable. A long summer permits the development of several generations, thereby very greatly increasing the nematode content of the soil.

Root-knot nematodes occur in greatest abundance in the light sandy soils of the South and Southwest, where they have the proper texture of soil combined with a desirable quantity of moisture, freedom from winter freezing, and a long, warm summer. The same combination of favorable conditions accounts for their very wide occurrence in greenhouses.

METHODS BY WHICH THE PARASITE IS SPREAD.

The larvæ of the nematode are capable of moving through the soil only very slowly, perhaps not more than a few feet each year. Yet this movement suffices to permit many of them to descend to a sufficient depth in the soil to escape drought and frost. It is not primarily by its own efforts, however, that the parasite is spread. It may be transported from field to field in a given district along with the soil that clings to agricultural implements, to the feet of domestic animals or man, or to transplanted plants. Too much care can not be exercised to prevent the distribution of infested plants or soil on plants to areas which are free from the pest. Garbage, manure, waste matter of any kind containing parts of diseased tubers or roots may spread the parasite and should never be placed on uninfested land. The pest is also frequently carried to other fields by means of surface water resulting from heavy rains. Irrigation water undoubtedly plays a very large part in the distribution of the disease in the semiarid districts of the West and Southwest. Again, it is probable that the organisms are carried from field to field by the dust storms which occur in some infested localities.

FIG. 15.—Root system of celery thoroughly infested with the root-knot nematode. To control this parasite at least a 2-year rotation with resistant crops is necessary.

The most common method of transporting the disease from one locality to another is through shipments of nursery stock, tubers,

bulbs, and seedlings. Numerous observations, particularly in the Southwest, have shown that peaches, figs, and Old World grapevines are the means by which new areas become infested. Florists and nurserymen have unwittingly been the cause of the disastrous spread of the parasite. The appearance of root-knot in new localities has repeatedly been traced directly to nurserymen who were not informed as to the nature of the disease. This suggests that no nursery stock should be accepted until it has been found free from nematodes, and if suspected of having come from infested districts it should be planted on a separate part of the farm until upon examination later it is found to be free from the trouble.

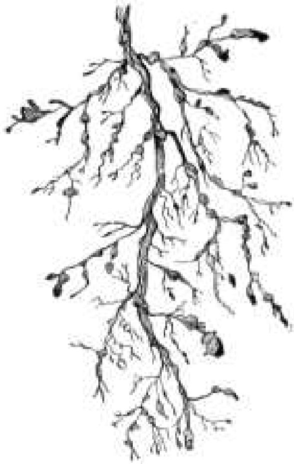


FIG. 16.—Root system of the Black Hamburg grape, showing small swellings due to the eelworm. The parasite causes much damage every year to many crops which the grower supposes are normal. (After J. C. Neal.)

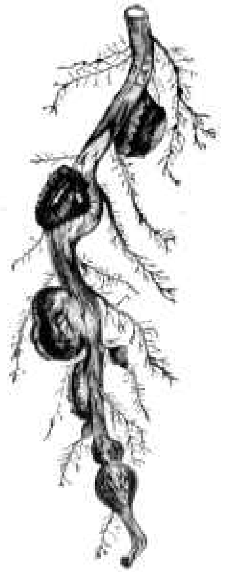


FIG. 17.—Roots of a weeping willow diseased with root-knot. Many ornamental plants are subject to this disease and should not be planted in soil known to be infested with the eelworm. (After J. C. Neal.)

FIG. 18.—Roots of the fig, showing swellings caused by the root-knot nematode. Most varieties of the fig are especially susceptible to the attacks of this parasite, which thrives in moist, sandy soils suitable for fig growing. (After J. C. Neal.)

In certain irrigated districts of California and Nevada seed potatoes (see figs. 4 and 5) have been chiefly instrumental in introducing and spreading the nematode. In attempting to control this disease it is absolutely essential that only uninfested tubers be planted. To use tubers showing no superficial evidences of the disease is not enough, but clean and healthy seed should be selected from fields where a critical inspection shows that root-knot has not been present. It naturally follows that potatoes which are to be used for seed purposes should be obtained from uninfested localities, preferably from States along the northern border of the United States from Minnesota to Maine, where the extreme temperatures practically prevent the occurrence of the nematode as an out-of-door pest.

In the South and East, cabbage, sweet potato, tobacco, and tomato plants (fig. 22), as well as various classes of nursery stock, such as the fig, peach, and mulberry, are means through which the parasite is known to be most frequently transferred into new localities. The prevalence of the pest in ginseng plantations is undoubtedly due to the transplanting of rooted seedlings from infested soil and to the use of seed which were packed in damp infested dirt.

METHODS OF CONTROLLING ROOT-KNOT.

Root-knot control is not as simple a matter as the control of some other plant diseases, inasmuch as the affected parts of the plants are entirely underground and therefore difficult to reach with protective materials. Control must of necessity consist not in the cure of plants that are already affected, which is practically impossible, but rather in the eradication of the pest from the soil. This may be accomplished directly by sterilization of the soil or indirectly by crop rotations designed to starve out the organism by cutting off the supply of food. A further control method consists of the development of resistant varieties.

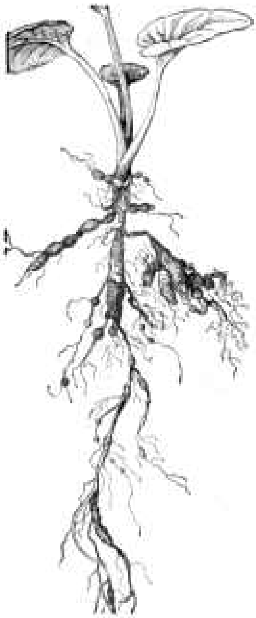


FIG. 19.—Primrose roots badly infested with the eelworm. Greenhouse soils kept at a mild, even temperature furnish excellent conditions for the growth and rapid increase of this parasite. (Drawing furnished by N. A. Cobb.)

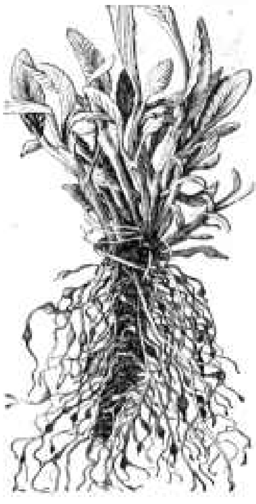


FIG. 20.—Chrysanthemum, the roots of which are infested with the eelworm. Plants severely attacked by this parasite are often dwarfed; they grow slowly and serve as breeding places for the nematode. (Drawing furnished by N. A. Cobb.)

FIG. 21.—Carnation plant, the roots of which are much distorted and swollen as a result of eelworm infection. Many greenhouse plants are similarly attacked when grown in soil which has not been sterilized. (Drawing furnished by N. A. Cobb.)

GREENHOUSES AND SEED BEDS.

Soil sterilization by one means or another is most often resorted to in greenhouses and seed beds. Many chemicals have been experimented with for this purpose, some with promising results, but their complete practicability has not yet been demonstrated. The application of heat has thus far been the most practicable method of killing the organism which causes root-knot.

A very common method of soil sterilization by heat uses perforated steam pipes. This consists of heating the soil by passing steam into perforated 1½-inch pipes laid lengthwise in the benches from 1 foot to 1½ feet apart and at a depth of 1 foot below the surface of the soil. Eighth-inch holes are made on the under side of the pipes at intervals of about 6 inches. The soil can be thoroughly heated in the course of an hour or more, depending on the steam pressure, until all nematodes, as well as most of the bacteria and other fungi which cause plant diseases, are killed. It has been found desirable to cover the soil with a canvas or a layer of straw held on by boards laid closely together, in order that the steam may not merely blow through the soil at certain points but may rather be distributed evenly throughout the bed. The higher the steam pressure, the more quickly the proper temperature is attained, with the further advantage that at high pressures the soils do not become so water-logged as they do if low-pressure steam is used. A convenient method often employed to determine whether the steaming has continued long enough is to bury potatoes at various points in the surface of the beds. When these are found to be cooked, one need have no fear that any nematodes will remain alive. Indeed, they probably perish long before the potatoes heat through.

STERILIZE WITH STEAM OR HOT WATER.

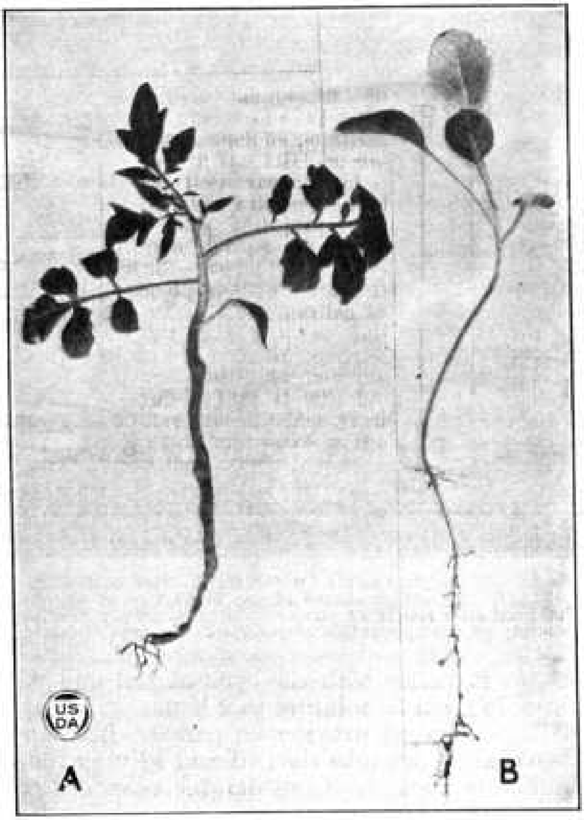


FIG. 22.—Tomato (*A*) and cauliflower (*B*) seedlings somewhat severely affected with root-knot. If cabbage, cauliflower, celery, lettuce, tobacco, tomato, or any other seedlings when taken from the seed beds or flats show even very slight infestation, they should be discarded: otherwise, the soil where they are planted is sure to become infested. Every knot on a root contains at least one female nematode, which may contain as many as 500 eggs.

Another way to steam-sterilize the soil, perhaps in even more wide use than that just described, is known as the "inverted-pan method." This has been described at length in Farmers' Bulletin 996, Steam Sterilization of Seed Beds for Tobacco and Other Crops, to which the reader is referred for detailed information. It consists essentially of an iron or wooden pan of convenient size for covering the entire width and considerable of the length of the beds, 6 by 12 feet and 4 inches deep being a common size. The pan is inverted over the bed and the edges thrust into the soil. To insure still further against the wastage of steam, soil is banked up around the edges of the pan. Then steam under pressure is turned into the pan through a special inlet. The length of treatment required must be learned by experi-

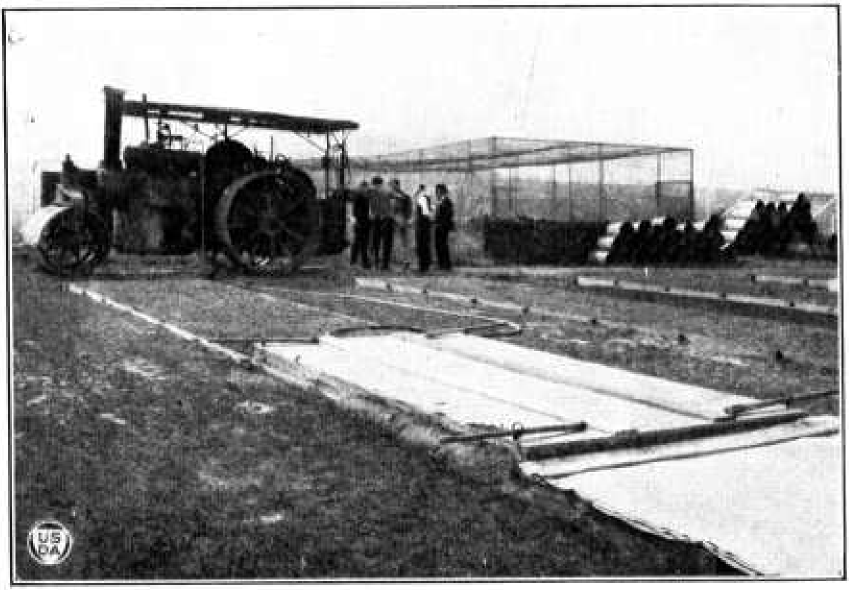


FIG. 23.—A complete outfit for the sterilization of tobacco seed beds by the steam-pan method. A traction engine or any other type of boiler, stationary or movable, may be used as a source of steam. The inverted-pan treatment is often followed immediately by the application of several thicknesses of canvas, to prolong the treatment.

ence, as it varies with the type of soil and with the steam pressure available from 30 minutes to 2 hours. The same test may be applied as that described previously, namely, inserting a potato to a depth of several inches into the soil and leaving the pressure on until it is completely cooked. Considerable economy of heat can be secured by immediately covering a newly sterilized section of a bed with heavy canvas. This not only conserves the heat for a longer period, but makes it actually penetrate deeper into the soil. Figure 23 illustrates a complete steam-sterilization outfit used in tobacco seed beds.

In case regular treatments by either of these methods do not appear to keep the pest in check, it is probable that it is because of one of two reasons: (1) It may be reintroduced in some manner each season, such as by way of the manure, compost, or new soil, by implements used previously in infested soil, by planting infested plants, or even by the water itself. The remedy in this case is to

guard against every possibility of reintroducing the pest. (2) Certain parts of the soil may have escaped treatment. For example, it is possible that large numbers of the organisms may have worked their way under the walks in their search for food, thereby escaping the treatment, and they may later work their way out again and reinfest the treated soil. This condition may be guarded against by such special treatment as the occasion may justify. Loosening the soil under the edges of the walks at the time of sterilization and giving a special treatment by means of a buried perforated steam pipe should give good results. Again, extending the edges of concrete walks to the very bottoms of the beds may be a suitable remedy.

A very convenient method for the use of steam where it is desirable to sterilize in pots and flats is to build a special vault or cabinet of concrete or tightly fitting lumber into which the soil may be rolled on trucks. The door should be so arranged as to close tightly. Steam may then be applied for two or more hours, the length of time varying with the pressure that is available and the tightness of the cabinet.

Still another application of heat as a sterilizing agent is its use in the form of hot water. While not so good as the steam treatments where steam is available, it is nevertheless effective in ridding the soil of the root-knot nematode and may be of considerable value to those unable to secure the use of steam. It may be applied either by immersing the pots in boiling water or by pouring the water directly into the pots, flats, or benches at the rate of about 7 gallons per cubic foot of soil. In this case several days must be allowed for the soil to drain before planting. This method is treated fully in Department Bulletin No. 818, Soil Disinfection with Hot Water to Control the Root-Knot Nematode and Parasitic Soil Fungi, which also contains an account of the experimental work upon which it is based.

All of these soil-sterilization methods and various modifications of them, which are treated more fully in Farmers' Bulletin 1320, The Production of Cucumbers in Greenhouses, are in practical use in the large commercial greenhouses.

Where steaming is impossible, greenhouses may still be freed from nematodes by removing the infested soil, whitewashing the benches with fresh boiling-hot whitewash and refilling them with fresh soil taken from some point where, by the observation of susceptible plants, it has been found that no nematodes are present. Fresh soil that is entirely or nearly free from the nematodes may be secured from low bottom land or any land that is flooded for a considerable period, preferably two to six months each year.

These methods apply, of course, only to beds which contain no living plants. It is impossible to formulate a rule of procedure that will be satisfactory in all cases in freeing beds of living plants from nematodes. If the plants are capable of being transplanted, they may be removed from the soil, washed, and all diseased roots cut off, cutting back the tops to correspond, and then transplanted to fresh soil. Before replanting it is well to soak the roots for half an hour or more in a solution of 1 part of 40 per cent formaldehyde in 100 parts of water, in order to kill any nematodes that may be present in the dirt adhering to the surface.

ORCHARDS.

When planning to set out a new orchard, it is highly desirable, where possible, to avoid land that is infested with the root-knot nematode. Presence or absence of infestation can usually be determined by examining the roots of such previous crops as are known

PLANT ONLY CLEAN NURSERY STOCK. USE IMMUNE COVER CROPS. FERTILIZE AND CULTIVATE THOROUGHLY.

to be susceptible (see p. 9), and even of weeds, many of which harbor the pest. Low-lying sandy areas, particularly those receiving the drainage from a hill above, are more likely to be infested than a hillside and are generally to be avoided. If the land is known to be infested it is far better to wait the required number of years to free it from the pest by growing immune crops than to risk ruining the trees by a heavy infestation of root-knot. Any of the resistant crops listed in the section headed "Plants not attacked" are good for this purpose. To plant very susceptible crops, such as melons, cucumbers, tomatoes, or the ordinary varieties of cowpeas, in a field that is later to be occupied by an orchard or other permanent crop is highly undesirable. The nematodes will multiply in great numbers on the susceptible plants and so infest the soil that the permanent crop will be seriously injured.

Where an orchard is free from the disease or nearly so, every effort should be taken to maintain this condition and avoid the necessarily expensive control methods. All nursery stock should be carefully examined and no tree planted that shows any sign of the disease on its roots. Only the resistant legumes listed in this bulletin should be used as summer cover crops. The bush velvet bean is coming to be more and more commonly used for this purpose. It is especially desirable, in that it is practically immune to root-knot and is one of the best soil improvers known.

Where only a few trees in a young orchard are affected (and this is often the case when partially infested nursery stock has been planted on uninfested land), they should be removed and destroyed. The surrounding soil, including an area well beyond that occupied by the infested roots of the removed tree, should then be loosened thoroughly and treated with a solution of formaldehyde (1 part of 40 per cent formaldehyde to 50 parts of water) at the rate of about 3 to 4 gallons per square yard. In this way the further spread of the disease is prevented, and nematode-free trees may be replanted after at least one year's delay with little fear of their becoming infested.

Where a large producing orchard is showing signs of deterioration on account of root-knot infestation the problem is a special one, and no entirely satisfactory treatment has been worked out. Peach growers often combat the disease with good success by "forcing" the trees to grow in spite of the presence of the pest. They cultivate thoroughly and apply an abundance of fertilizer, particularly stable manures and commercial nitrogen-bearing fertilizers rich also in

potash, so that the roots are made to grow faster than the nematodes can produce knots. The use of immune legumes as cover crops is particularly recommended in infested orchards. Aside from being a good horticultural practice from the point of view of the addition of humus and nitrogen to the soil, a good crop of immune legumes is beneficial in that it keeps in check the weeds that are hosts to the nematodes. Commercial peach growers of Georgia and adjoining States are handling the situation by these methods and maintaining a high degree of productivity in their orchards. Where these control measures are not consistently followed, however, the renewed vigor results in only a temporary relief, as the new root growth subsequently becomes invaded by the parasite and the plant is reduced to a state of nonproductiveness.

One means of preventing root-knot in peach orchards practiced in certain parts of Florida is that of grafting the peach on the native wild plum. This method has proved successful from the standpoint of the disease, because the wild plum is resistant to root-knot. As a general horticultural practice, however, grafting the peach on the wild plum has not given satisfactory results.

FIELDS NOT USED FOR PERMANENT CROPS.

The most satisfactory method of combating root-knot is that in which the infested fields can be planted to nonsusceptible crops for a period of years. To be sure, nematodes can be starved out entirely in two years or a little more if the ground is kept absolutely free from vegetation of all kinds, but this is impracticable on a large scale and in many regions, because of the consequent erosion of the soil, the leaching out of the food substances, and the money loss due to the nonproductivity of the field for that period. However, by making use for about three years of a rotation in which the plants used are not susceptible to the disease, the cost of controlling the nematodes may be considerably reduced, while the land may be actually enriched. Not only is the nematode subjugated by the proper system of rotation, but the same is true of other plant diseases which increase from year to year when the land is repeatedly planted to one crop. As a general agricultural practice, rotation has everywhere proved a necessity to successful farming.

ROTATE.
STARVE OUT THE NEMATODES
BY GROWING IMMUNE CROPS.

The rotations that have been found to be desirable are those in which a summer leguminous crop, with or without corn, alternates with a winter grain. In making these rotations it is, of course, necessary that the crops grown in the summer be free from the attacks of the root-knot nematode. By using leguminous crops the land is enriched while the process is being carried on, and by selecting the proper crops the rotation can be carried on at a profit. The summer crops which have been found most satisfactory for this purpose are corn, velvet beans, Florida beggarweed, the Laredo soy bean,

and cowpeas of the Iron, Brabham, Victor, or Monetta varieties, which are highly resistant. Corn should be planted at the usual time in early spring and followed later by velvet beans or one of the resistant varieties of cowpeas, which are drilled between the corn rows. Corn and cowpeas or bush velvet beans planted in this manner make a very desirable combination, as they permit clean cultivation. Of the legumes, beggarweed has the disadvantages that the seed is expensive and that its growing season is so long that it does not permit seed production except in the extreme Southern States. In certain parts of Florida even the resistant cowpeas are subject to injury by root-knot. While this injury is not severe enough to destroy the plants, it is yet inadvisable to grow even these resistant varieties in such places, since by so doing the nematodes are increased. In other parts of the South the only disadvantage of using cowpeas lies in the difficulty of securing unmixed seeds of the resistant varieties. If seeds of other varieties are present, abundant infestation will result. In such sections the velvet bean is especially valuable because of its practically complete immunity to root-knot. Farmers' Bulletin 962, Velvet Beans, deals with this crop, which has become increasingly important as a forage plant and soil improver throughout the southern part of the United States, some varieties doing well even as far north as Virginia. Corn and velvet beans are frequently grown together, this combination being a particularly good one in so far as root-knot control is concerned. The four legumes mentioned, namely, beggarweed, velvet bean, the resistant soy bean, and the cowpea (resistant sorts), seem to be the best that can be recommended, although the Spanish peanut appears also to have qualities which should fit it for similar use. By referring to the list of immune plants it will be seen that other immune summer crops could be used, such as sorghum, millet, Natal grass, or redtop.

The two most successful winter crops in the South are winter rye and winter oats, although the latter does not seem to be satisfactory on many of the very light, sandy soils. In certain latitudes the grain may be allowed to ripen; then the velvet beans or beggarweed should be sown. This should be harvested in time to permit the ground to be prepared for sowing the winter grain or else pastured for the winter.

In view of the above facts, the following rotations are suggested for fields infested with root-knot: In the fall sow winter rye so early that it can make a good growth before it is necessary to plow the land for the next crop. Turn under the rye as green manure in early spring and plant corn, later placing resistant cowpeas in the drill between the rows. The second fall sow winter grain, preferably oats, which may be allowed to ripen or may be cut for hay while green. Follow this with one of the resistant varieties of cowpeas, which can be sown broadcast, or, better, in 2-foot drills, where they can be cultivated. Harvest the cowpeas as hay, and if a 3-year rotation is desired sow winter grain, allow it to ripen, and again broadcast a resistant cowpea to be cut as hay. Barley or wheat may be substituted for the oats and rye, and (in the second and third years) velvet beans or beggarweed may be used instead of cowpeas. Where the velvet bean is used it is often left on the ground all winter as winter pasture for hogs or cattle.

It is possible to starve out the nematode by the 2-year rotation if it is carried on very carefully. However, it seems better, where possible, to use the 3-year rotation. The completeness with which the nematodes are exterminated by the process here outlined depends largely upon the care with which the work is performed. Thus if weeds or volunteer plants from a previous susceptible crop, such as Irish potatoes, are allowed to be present during the summer, the nematodes may be harbored by these and the extermination will not be complete. If the field is subject to overflow by surface water from adjacent infested land, fresh infestation will be the result and the value of the rotation will be lost. The same result will follow if infested soil is introduced on plows, cultivators, wagon wheels, horses' hoofs, etc. It would be desirable to dig a ditch 2 feet wide and a foot or two deep along those sides of the field that border infested fields which are higher up. Besides preventing overflow, the ditch will make a kind of natural boundary, across which animals or implements should not be allowed to go.

In regions of general infestation, as in many parts of the South, the reinfestation of fields which have been freed of nematodes is very likely to occur. For this reason it is desirable to introduce a two-year or three-year nematode-extermination rotation, such as that outlined above, at least every three or four years. In this way serious infestation is prevented. In such a rotation it is desirable to plant the most susceptible crops immediately after the field has been cleared of nematodes and to follow them by those which are less susceptible until the time comes to apply the extermination rotation again.

Pineapple growing is a rather specialized industry which has the root-knot nematode to combat. A disease known as red wilt is due largely to this organism. This disease and its successful control by crop rotations is treated fully in Farmers' Bulletin 1237, Pineapple Culture in Florida. Ginseng, another very specialized crop, is also subject to root-knot unless special measures are taken to avoid it. Such measures are dealt with in Farmers' Bulletin 736, Ginseng Diseases and Their Control.

HOT-WATER TREATMENT FOR DASHEENS.

Dasheens, like potatoes, are affected by the penetration of the organism directly into the tuber itself. Tubers so infested, even though very slightly, should not ordinarily be used for seed, since they would carry the disease with them. In the case of dasheens, however, a hot-water treatment has been worked out which makes it safe to use slightly infested tubers without danger of spreading the organism.

TREAT SEED DASHEENS
40 MINUTES AT 122° F.

The treatment consists of immersing the tubers for a period of 40 minutes in water kept at a temperature of 122° F. If the temperature of the water falls below this for more than a few moments the nematodes may not be killed, and if it rises above 126° F. the tubers may be injured.

For the best temperature control a rather large volume of hot water is desirable, and an accurate thermometer should be kept suspended in it so that the temperature can be determined instantly at any time during the treatment. The temperature may be regulated by keeping a low fire under the vessel or by adding hotter water when needed and cold water when the temperature rises above the danger point.

Dasheens should be treated while dormant, since after they begin to sprout they are more easily injured by the hot water. For this reason, when they are not planted very early it is advisable to treat the tubers several weeks in advance of planting.

To avoid danger of introducing root-knot into land not already infested with it, all dasheens to be planted should be treated as above unless they are known to have been carefully examined at the time of digging and the fibrous feeding roots found free from all evidence of this disease. This examination to be of value must be made of the fresh roots, for it is only then that the characteristic "knots," galls, or swellings are easily and certainly recognized. Examination of the tubers at any other time is useless unless the infestation with nematodes is severe enough to cause distortion, in which case the tubers are not fit for seed.

THE HOME VEGETABLE GARDEN.

The southern home garden, especially in the sandy sections, is very generally, if not almost always, badly infested with root-knot, and because of the usual custom of having the garden in the same place year after year, combined with the fact that most garden vegetables are especially subject to nematode injury, it is relatively difficult to apply ordinary rotations successfully as a control measure.

> ROTATE
> CHICKEN YARD,
> VEGETABLE GARDEN,
> AND CORN PATCH.

For the southern home gardener who has had poor results with his summer vegetables due to root-knot, a special 3-year rotation has been worked out that has several points of advantage. It involves a rotation of the garden with the chicken yard, and assures better results with both. Only annual crops can be considered in this rotation. Perennials susceptible to root-knot, such as grapes and figs, must be planted in a separate area. The following plan or some modification of it suitable to special conditions is advised:

The back yard is divided into three parts lengthwise by means of woven-wire chicken fencing. The slope of the land should be such that there can be no drainage from one plat into another. The three parts may be designated A, B, and C (fig. 24). The chicken house is to be located in the middle at one end, as shown in the diagram, so that it can be made to open into any one of the three at will. Simple trap-door arrangements, as indicated in Figure 24, will provide for this. Leaving only one door open at a time, therefore, will permit the chickens to roam in only one yard.

The first year, say 1923, the garden is planted in plat A. The chickens are turned into plat B and are kept there as long as the garden is maintained. In plat C are planted only crops immune to root-knot, such as sweet corn for the home table. Cowpeas of the resistant varieties or velvet beans may be grown between the rows, and the soil will be improved. As early as possible

in the fall a winter grain, such as Abruzzi rye, should be sown. This helps to keep down weeds that are susceptible to root-knot, and the rye affords valuable feed for the chickens in the spring.

Now rotate the fields each year. At garden planting time in the spring the chickens should be turned into the rye in plat C, where they will find good feeding for quite a while. If the flock is large enough the chickens will keep the ground bare of vegetation all summer long, and that is where they get in their good work of ridding the soil of the root-knot organism. Without a host plant the nematodes will die. Do not spoil the good results by throwing any nematodes over the fence to the chickens, either in the roots of even mildly attacked garden plants or in parings from affected plants, such as potatoes, used in the kitchen, unless they are cooked.

Plat A will be planted to corn and other immune crops in 1924 and serve as the chicken yard in 1925. Plat B will grow the garden in 1924 and will be followed in 1925 by the corn and other immune crops. Plat C will become the chicken yard in 1924 and serve as the garden the following year. After the two years of freedom from susceptible crops which this plat will then have had, the improvement with respect to nematodes will be evident.

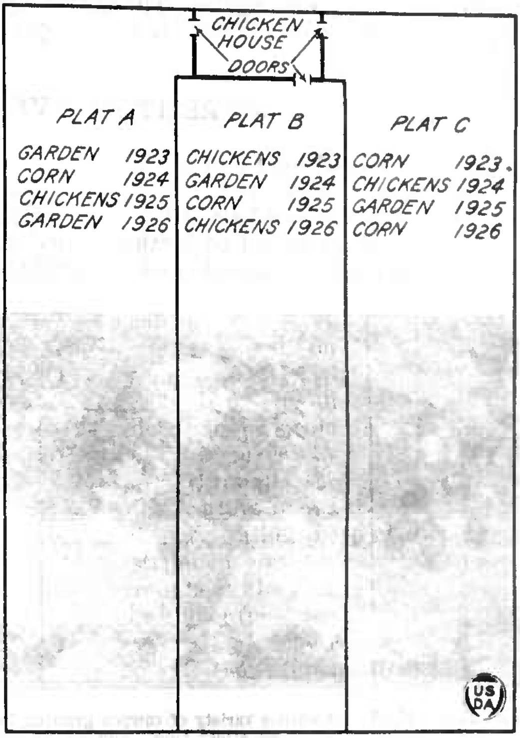


FIG. 24.—Plan of a home-garden, chicken-yard, and corn rotation which can be applied to available ground of almost any dimensions. Note the chicken house with doors opening into the three yards. A badly infested garden can be entirely freed from the root-knot nematode by applying the above rotation.

PREVENTION OF SOIL INFESTATION EASIER AND CHEAPER THAN CURE.

Root-knot has become so widespread that it seems but a question of time until all lands where conditions are favorable will become infested unless special precautions are taken. First of all, the means by which the parasite is spread, listed on page 12, should be constantly guarded against. Particular care should be taken not to introduce the pest on seedling plants, bulbs, tubers, or nursery stock. Then the dangerous practice of growing susceptible crops year after year on the same ground should be stopped. As a preventive measure the crop rotations are especially recom-

KEEP YOUR FIELDS FREE
AND AVOID LOSS AND EXPENSE.

mended. They are even more certain to be productive of continuously good results in this connection than where they are used after infestation has already become severe, for in this latter case it is very easy to overlook susceptible weeds or volunteer plants from previous seasons that may keep the organisms alive until the susceptible "cash crop" is planted again. The old saying, "An ounce of prevention is worth a pound of cure," is especially applicable in the case of root-knot control.

SELECTING RESISTANT VARIETIES.

Among the cultivated crops certain strains or varieties are known to be highly resistant, if not immune, to nematode attack. These are (1) the Iron, Brabham, Victor, and Monetta varieties of cowpeas, which, if not mixed with other varieties, possess a high degree of resistance; (2) the Laredo and three other varieties of soy beans

Fig. 25.—A highly susceptible variety of cowpea growing in the two middle rows, with more resistant varieties on either side. The susceptible variety was almost completely killed by root-knot, while the resistant varieties stood up vigorously.

as yet not named; (3) American grapes, which are much more resistant than European varieties; and (4) certain kinds of figs (for example, the Celeste and Poulette are claimed to be less susceptible than other varieties). Hence, it is desirable that the more resistant strains be grown wherever possible, since this not only reduces the number of nematodes present in the soil but also insures better crops. Figure 25 illustrates differences in the susceptibility of cowpea varieties, while the striking resistance of the Laredo soy bean is shown in Figure 26.

As most of the above strains have been obtained by careful selection and breeding, it seems quite likely that other immune varieties can be developed in a similar way from crops which are now susceptible. Every farmer should be able to practice a simple selection, that is, when any plants in an infested field come up to standard in every way, are especially vigorous, and show freedom from root-knot, they should be marked and their seeds harvested separately. These seeds should be planted on infested land and similar careful seed selection should be made from the resulting disease-free plants.

More complicated breeding work, especially the crossing of immune upon susceptible varieties, is not advisable for the average farmer, on account of the time and expense.

As the most satisfactory and economical method of controlling root-knot depends upon the proper system of rotation with immune varieties of plants, it is highly important to keep pure the strains that are already known to be resistant and to strive to improve them by still further selections. Special care should be taken to prevent their crossing with susceptible varieties. Without these precautions even the best resistant sorts have been known to break down under severe root-knot conditions. It is also important that new strains of resistant crops be developed.

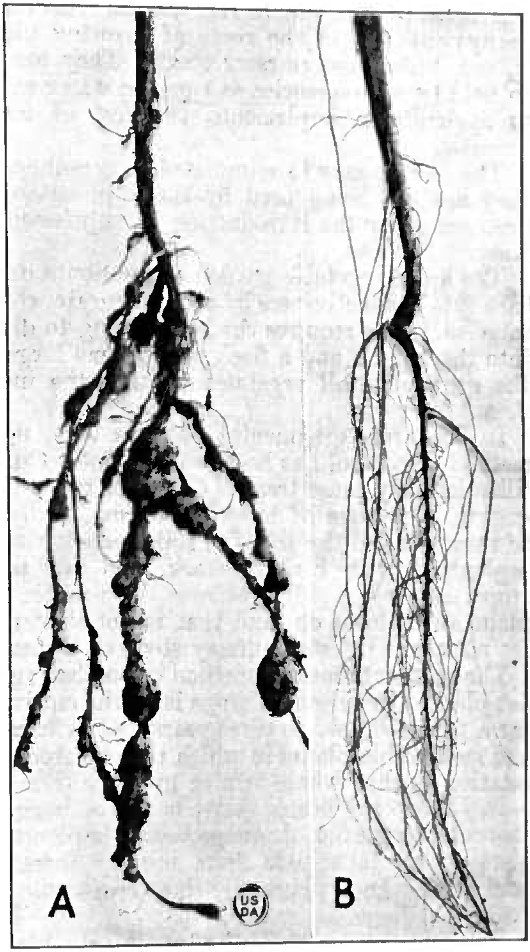


Fig. 26.—Roots of the Peking soy bean (*A*), a variety susceptible to root-knot, compared with those of the resistant variety Laredo (*B*). These plants were grown at Brooksville, Fla., under identical root-knot conditions. The resistant varieties are not always as free from the disease as is shown here.

SUMMARY.

A serious disease of plants known under the names of root-knot, root-gall, and big-root, causes immense damage in all except the most northern parts of this country.

The parasite causing the disease is a minute nematode, or eelworm (*Heterodera radicicola*), which multiplies very rapidly under favorable conditions. The life cycle may be completed in about four to five weeks, and each female may lay as many as 500 eggs. When invaded by the worms, roots become enlarged, distorted, or deformed, resulting in a hindrance to the growth of the plant.

Root-knot flourishes best in light, sandy soils which are moist and warm. It can not thrive in heavy soils or in those that are constantly wet.

Most crops are susceptible to the attacks of the disease. Some, however, are resistant. The most important of these are the Iron, Brabham, Victor, and Monetta cowpeas, corn, barley, beggarweed, rye, redtop, sorghum, the Laredo soy bean, timothy, velvet beans, wheat, and winter oats.

The nematodes may be transported from one locality to another in many ways, as in the roots of growing plants and by means of tubers, bulbs, and nursery stock. They can be carried from field to field by such agencies as running water and the soil which clings to agricultural implements, the feet of men, and the hoofs of animals.

The disease may be eliminated in greenhouses and seed beds when they are not being used by the application of steam under high pressure or by the introduction of uninfested soil into clean whitewashed benches.

The home vegetable garden of the South can very well be brought back into productiveness by a special grain, chicken-yard, and garden rotation. This requires chicken fencing to divide the available land into three parts and a flock of chickens large enough to keep down the growth of all vegetation within the inclosure designated for them.

In orchards, ornamental gardens, etc., no entirely satisfactory method of control has been worked out. Cultivation and high fertilization may cause trees to overcome the trouble by inducing rapid growth. In cases of local infestation, badly diseased trees should be removed and the infested soil treated with formaldehyde before replanting with healthy stock. Do not plant susceptible cover crops, as they rapidly increase the number of nematodes. Never plant an orchard on land that is not known to be nematode free. Do not plant infested nursery stock on either clean or infested soil.

The most satisfactory method of combating the nematode in fields not planted to perennial crops is by the cultivation of immune crops for a period of two to three years and by carefully killing all weeds and susceptible plants in which the nematode can live. A desirable rotation is that where winter grains alternate with resistant cowpeas, Laredo soy beans, velvet beans, or beggarweed. Care must be exercised to prevent drainage water, implements, animals, etc., from bringing the nematode from near-by infested fields. In ridding land of root-knot, plant only those crops which are known to be free from the disease.

Starving the nematodes by keeping the land free from all vegetation for two years is an effective control method, though often impracticable.

ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE.

Secretary of Agriculture	HENRY C. WALLACE.
Assistant Secretary	C. W. PUGSLEY.
Director of Scientific Work	E. D. BALL.
Director of Regulatory Work	
Weather Bureau	CHARLES F. MARVIN, *Chief.*
Bureau of Agricultural Economics	HENRY C. TAYLOR, *Chief.*
Bureau of Animal Industry	JOHN R. MOHLER, *Chief.*
Bureau of Plant Industry	WILLIAM A. TAYLOR, *Chief.*
Forest Service	W. B. GREELEY, *Chief.*
Bureau of Chemistry	WALTER G. CAMPBELL, *Acting Chief.*
Bureau of Soils	MILTON WHITNEY, *Chief.*
Bureau of Entomology	L. O. HOWARD, *Chief.*
Bureau of Biological Survey	E. W. NELSON, *Chief.*
Bureau of Public Roads	THOMAS H. MACDONALD, *Chief.*
Fixed Nitrogen Research Laboratory	F. G. COTTRELL, *Director.*
Division of Accounts and Disbursements	A. ZAPPONE, *Chief.*
Division of Publications	EDWIN C. POWELL, *Acting Chief.*
Library	CLARIBEL R. BARNETT, *Librarian.*
States Relations Service	A. C. TRUE, *Director.*
Federal Horticultural Board	C. L. MARLATT, *Chairman.*
Insecticide and Fungicide Board	J. K. HAYWOOD, *Chairman.*
Packers and Stockyards Administration *Grain Future Trading Act Administration*	CHESTER MORRILL, *Assistant to the Secretary.*
Office of the Solicitor	R. W. WILLIAMS, *Solicitor.*

This bulletin is a contribution from

Bureau of Plant Industry	WILLIAM A. TAYLOR, *Chief.*
Office of Cotton, Truck, and Forage Crop Disease Investigations	W. A. ORTON, *Pathologist in Charge.*

WASHINGTON : GOVERNMENT PRINTING OFFICE : 1923